

Influence the Mechanical and Thermal Properties of Thermoplastic Polyurethane -Reinforced Polyester Composite

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ABSTRACT

An investigation was conducted to analyze the impact of incorporating polyurethane polymer's particles at different weight ratios (0.5, 1, 3, 5, 7,10 and 15) wt. %, on the polyester polymer's mechanical properties and thermal conductivity coefficient. The thermal conductivity coefficient of the samples was calculated using Holmarc's Lee's Disc apparatus device. The mechanical properties like compressive, tensile, and bending strengths were measured using a universal machine. The results indicated that increasing the polyurethane foam (PU) ratio leads to an improvement in the thermal insulation ability due to a decrease in the value of thermal conductivity, the addition of polyurethane foam enhances the ability of thermal conductivity at the ratio 7 wt. %, with a value equal to 0.175 W/m °C, by increasing the thermal conductivities of the sample, while the result indicated a decrease in the thermal conductivity at the ratio 15 wt. %, with a value equal to 0.155 W/m °C. Also, adding these percentages led to a rise in the values of the mechanical qualities represented by the elongation, especially at the ratio of 10 wt. %, with a value equal to 1.9 %, and tensile strength increases at a ratio of 15 wt. %, with values equal to 18.9 MPa.

Keywords: polyurethane foam, Polyester polymer, mechanical properties, thermal conductivity, polymer.

INTRODUCTION

Polyurethane is one of the important polymers in many applications and Tritosil Polyurethane is one component with Highly resistant to seawater-diluted acids and alkalis, odorless, Non-sag, -moisture-cure polyurethane sealant designed to skin and cure rapidly, outstanding UV resistance and long term durability [1]. Polyurethane is widely used in several industries, including construction, packaging, and furniture. The remainder of the polyol chain, which is flexible, and hydrogen bonds, which are rigid, make up polyurethane [2]. Since the Inflexible PU foam's hardness rises with density, foam with better properties is produced. More specifically, an increase in density of (1000 g/cm³) suggests an increase in hardness of approximately (100 Pa) [3]. Fig. 1, shows the chemical composition of polyurethane. Adding materials (polymer) to polymers is a rapid and inexpensive approach to changing the properties of basic materials; as a result, the mixture (copolymers) was and still is of interest to interest of researchers in the field of scientific research, particularly in the industry [4]. Polyester polymer has been added to polyurethane polymer. Unsaturated polyester resins are used in civil structural engineering applications, automotive paints, construction, piping, protective coatings, composites, storage tanks, and ship materials, which require fire resistance, ductility properties, and high strength [5-6]. Polyester is the most produced thermoplastic polymer and has many applications, such as textile fibers and bottles. The polyester used in textiles is generally polyethylene terephthalate with well-known properties of chemical inertness, lightness, good process ability, high-melting-point, high tenacity, and low cost [7]. This study aims to evaluate the effect of incorporating polyester fibers/fabrics into a thermoplastic polyurethane (TPU) matrix, focusing on enhancing its mechanical performance and thermal stability.

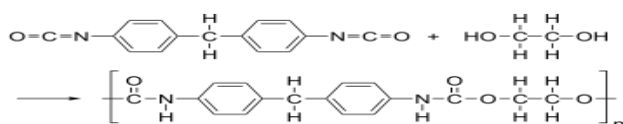


Figure 1: Chemical composition of polyurethane [8-9].

MATERIALS AND METHODS

The trimethylamine (TEA) was used as a catalyst in the reaction of 1:1 weight percent isocyanate and (polyester-polyol) provided by Sigma-Aldrich Company. Polyurethane was prepared, also added drops of water to release carbon dioxide, which worked to generate cellular gaps inside the mass of the mixture. The polymer (polyester) used in this study was supplied as a basic material by (Henkel A.S.) company (Turkey). The polymer used in various industries is a brown viscous liquid with a strong and distinctive effect, with a density of about 1.5 g/cm³, viscosity of 1000 (p) at about 25 °C. The solid phase is diverted after the addition of ethyl ketone peroxide liquid, which is a transparent thick liquid and fig. (2) shows the graph of the chemical composition of unsaturated polyester,

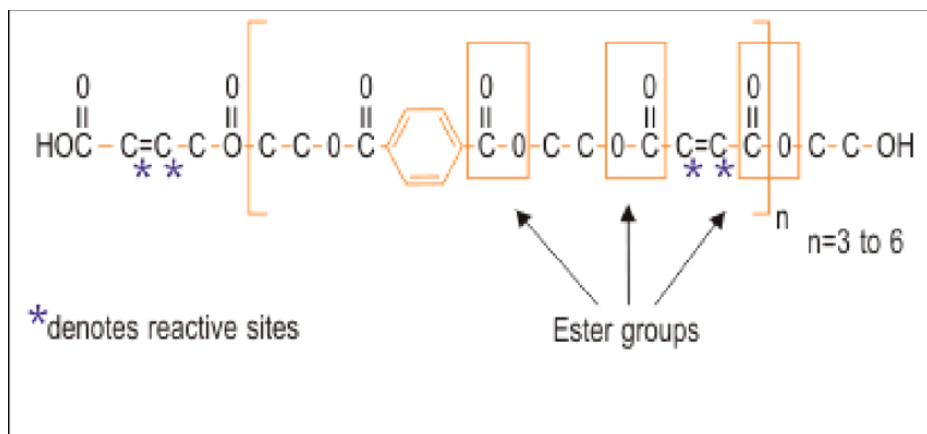


Figure 2: Diagram of chemical structure for unsaturated polyester [10-12].

The copolymer samples were prepared from Polyurethane with polyester at laboratory temperature. Then, we have been added different weight ratios (0.5, 1, 3, 5, 7, 10 and 15) wt% of Polyurethane to the copolymer mixture. The mixing procedure was continued for the mixture was evenly distributed, then, the final product was poured into a cylinder mold, circular and rectangular. Fig.2 shows the Tensile, thermal conductivity and compressive strength test samples [10].

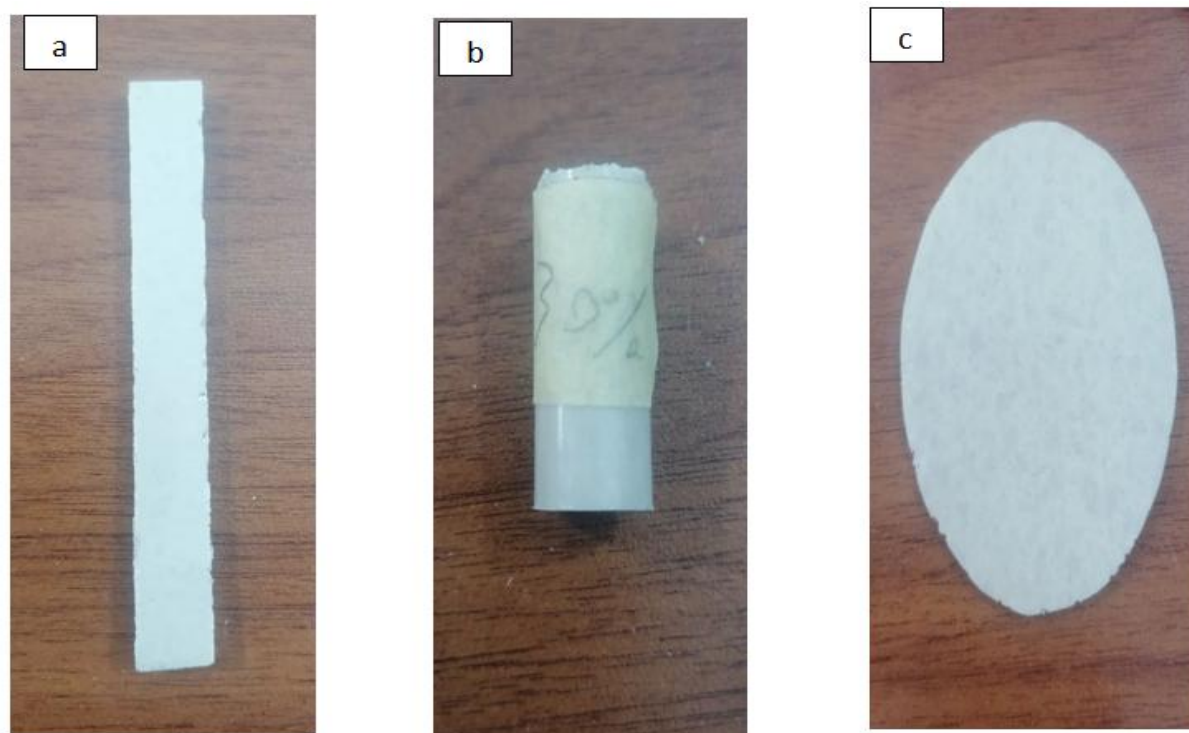


Figure 3: Tensile, thermal conductivity and compressive strength test samples: (a) rectangular slab, (b) cylindrical, (c) circular.

Evaluation of mechanical and thermal properties

A German made tensile instrument (Zwick Rell, type (BTI-FR2.5 TN.D. 14), which measures the mechanical properties (tensile strength, compression resistance, bending resistance), was used to test the polymers models show a Figure 4a The mechanical properties measuring device (Tensile). Tensile strength(Q) can be calculated using Eq. (1).

$$Q = \frac{F (N)}{A(mm^2)} \quad (1)$$

Where, F is cutting force (Newton), A is cross-sectional area (mm²).

The relationship (Young's modulus) Y = (Max Stress) / (Max Strain) (MPa)

Was used to compute the young modulus.

The thermal conductivity coefficient (K) of the samples was calculated using a done by the Holmarc's Lee's Disc apparatus model HO-AE-LD18 (Kochi, India, Holmarc Opto-Mechatronics Ltd manufactures). Figure 4b shows the Hilmarc's Lee's Disc apparatus for thermal conductivity measurement. Eq. (2) was used to calculated thermal conductivity (K) using Fourier's law.

$$K = - \frac{q x}{A \Delta T} \quad (2)$$

Where: K is thermal conductivity (W/m.K°), q is Heat energy (W), T is temperature (°K), x is thickness of test specimen (m), and A is area of test specimen (m²).

At the steady state, the thermal conductivity K is calculated using Eq.(3).

$$K = \frac{MC \frac{dT}{dt}}{\pi r^2 (T_2 - T_3)} \times \frac{(r+2h)x}{2(r+h)} \quad (3)$$

Where, M is mass of the metallic disc, C is specific heat capacity of the metallic disc, h is height of the metallic disc, r is radius of the metallic disc, $\frac{dT}{dt}$ is rate of cooling of the metallic disc at T₃, (T₂ – T₃) is the temperature difference across the sample thickness (x), Diameter = 76.2 mm, Thickness = 4 - 6 mm for Sample dimensions.

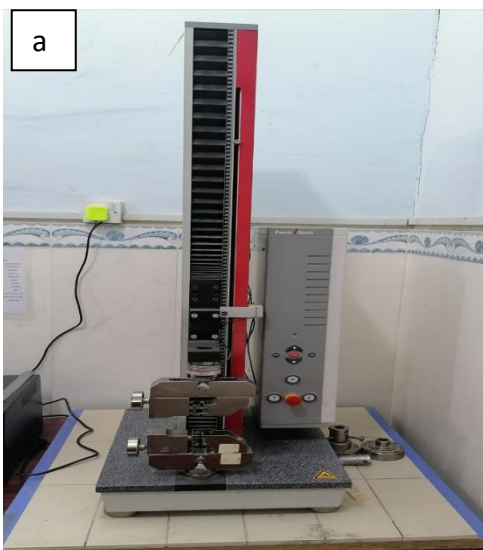


Figure 4: Devices are used to evaluate the specimens: a – mechanical properties measuring device (Tensile); b – Hilmarc's Lee's Disc apparatus for thermal conductivity measurement

RESULTS AND DISCUSSION

The relationship between the tensile force (stress force) and the proportion of the polymeric additives is depicted in Figure 5. The evaluation of stress (as a function of filler content) revealed a distinct non-linear behavior across the investigated weight percentages. At minimal loading levels 1–%0.5) wt ,(%the composite exhibited its highest stress values, reaching approximately 29.5 MPa .However, increasing the filler content to 3 wt % resulted in a sharp reduction in stress, dropping to a minimum of 8.5 MPa .This pronounced decrease can be attributed to filler agglomeration and phase incompatibility at this critical concentration, which induces localized stress concentration sites that impair the load-bearing capacity of the matrix. Beyond 3 wt ,%a progressive recovery in stress was observed, increasing steadily from 5 wt %up to 19 MPa at 15 wt .%This positive trend indicates enhanced filler dispersion and improved interfacial adhesion, facilitating more efficient stress transfer across the polymer matrix at higher loading levels.

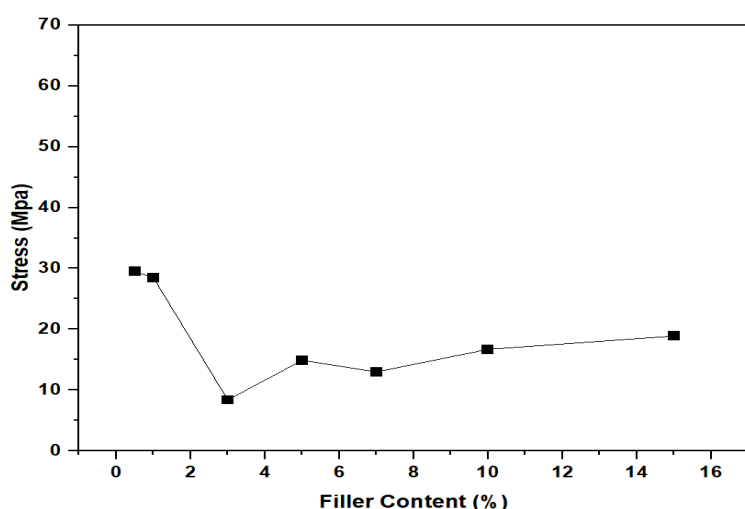


Figure 5: The relation between tensile strength and the filler content.

Figure 6 shows the polymer elongation model with concentration. The percentage elongation as a function of filler content exhibited a non-linear and fluctuated pattern, reflecting the filler's effect on matrix flexibility and chain mobility. At low loadings (0.5% - 1wt.%), the composite demonstrated its maximum elongation of 2.5%. However, increasing the filler content to 3wt. % caused a sharp drop to a minimum elongation of 1.1%. This significant decline in ductility is primarily attributed to restricted polymer chain mobility and filler agglomeration, which act as stress concentration sites that initiate early brittle failure. Within the range of 5% to 15wt.%, the elongation showed slight recovery and fluctuated between 1.3% and 1.9%, recording a secondary peak at 10 wt.%(1.9%). This behavior illustrates a competitive interaction between localized filler dispersion that slightly aids load absorption and the overall physical hindrance imposed by higher filler loadings on the matrix polymer chains.

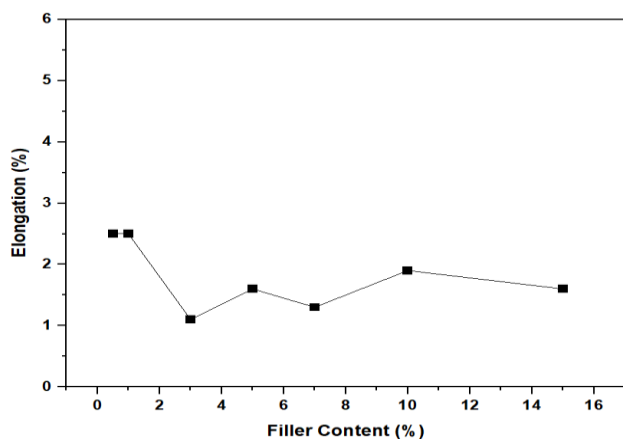


Figure 6: The relation between elongation and the filler content.

The experimental data displayed in the figure 7 reveals a significant enhancement in the compressive strength of the polymer composite as a function of the filler content. The baseline polymer exhibited a compressive strength of approximately 80 MPa. A sharp and rapid surge was observed between 5 wt.% and 10 wt.%, reaching around 220 MPa, after which the values approached a plateau stage at 15 wt.% with a maximum strength of nearly 230 MPa. This substantial improvement can be primarily attributed to the efficient stress transfer mechanism from the polymer matrix to the filler particles, which effectively bear and distribute the applied compressive loads. Furthermore, strong interfacial adhesion between the filler and the matrix minimizes internal voids and structural defects. The presence of the additive also restricts the mobility and slipping of the polymer chains under mechanical compression, thereby increasing the overall stiffness and structural integrity of the composite. The leveling off observed at higher loading fractions >10 wt.% indicates a saturation effect and potential particle agglomeration, which limits further enhancement of the mechanical properties.

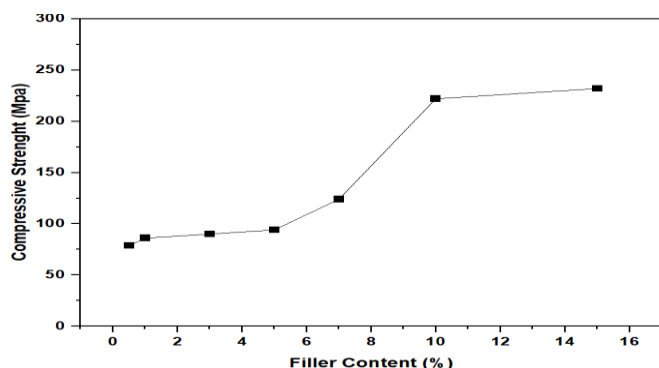


Figure 7: The relation between the compressive strength and the filler content.

The experimental results depicted in Figure 8 demonstrate a clear linear inverse relationship between the thermal conductivity coefficient and the weight fraction of polyurethane added to the polyester matrix. The pristine polymer exhibited the highest thermal conductivity at approximately 0.19 W/m·K. However, a gradual and steady decline was observed as the polyurethane concentration increased, reaching a minimum value of 0.155 W/m·K at 15 wt% filler content. This reduction in thermal conductivity can be primarily attributed to the inherently superior thermal insulation characteristics of polyurethane compared to polyester. At the microscopic level, thermal transport in non-crystalline polymers predominantly relies on lattice vibrations (phonons). The inclusion of polyurethane introduces hetero-polymer interfaces that enhance phonon scattering, thereby impeding heat transfer through the matrix. Furthermore, the disruption of the structural ordering within the polyester chains likely promotes the formation of amorphous regions, which further suppresses thermal conduction. Overall, these findings highlight the potential of integrating polyurethane to enhance the thermal insulation performance of polyester-based composites.

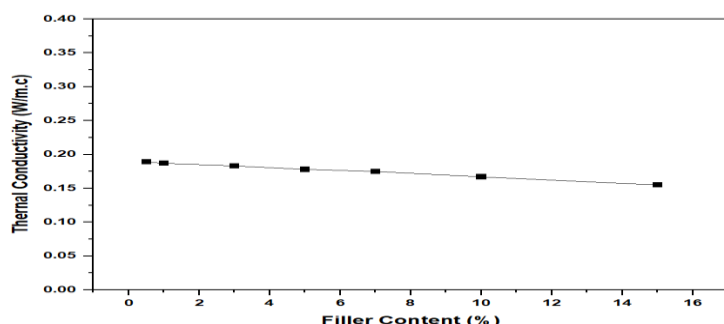


Figure 8: shows the relationship between the thermal conductivity and the filler content.

CONCLUSION

We conclude that adding polyurethane to polyester has a significant impact on the mechanical properties and thermal conductivity coefficient. The results indicated that increasing the polyurethane foam (PU) ratio leads to an improvement in the thermal insulation ability due to a decrease in the value of thermal conductivity, the addition of polyurethane foam enhances the ability of thermal conductivity at the ratio 7 wt. %, with a value

equal to 0.175 W/m °C, by increasing the thermal conductivities of the sample, while the result indicated a decrease in the thermal conductivity at the ratio 15 wt. %, with a value equal to 0.155 W/m °C. Also, adding these percentages led to a rise in the values of the mechanical qualities represented by the elongation, especially at the ratio of 10 wt. %, with a value equal to 1.9 %, and tensile strength increases at a ratio of 15 wt. %, with values equal to 18.9 MPa.

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